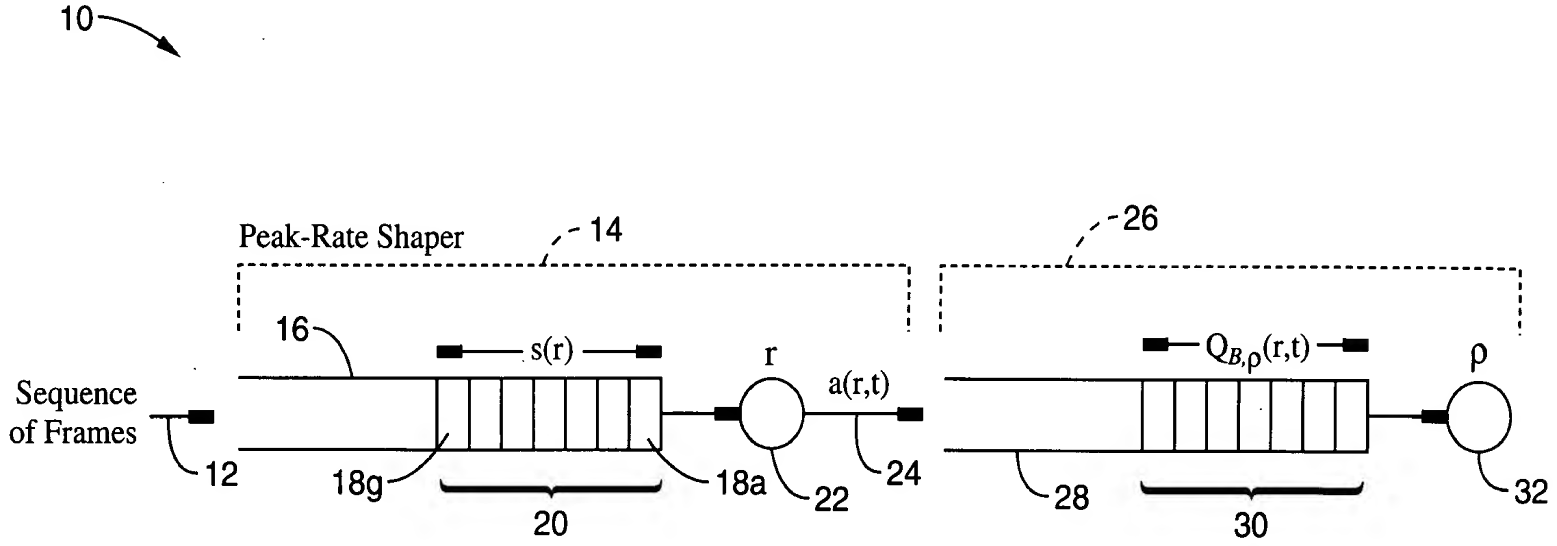
10
Peak-Rate Shaper
14
26
16
s(r)
r
a(r,t)
$Q_{B,\rho}(r,t)$
ρ
Sequence of Frames
12
18g
20
18a
22
24
28
30
32

FIG. 1

#7

```
/* =================================== */
/* ========== Compute Active Periods =========== */
/* ======== for an Elementary Video Stream ========= */
/* =================================== */
/* Index i denotes the i-th frame, $q_i$ denotes the queue size at the instant
   just after the i-th frame arrival and index j denotes the j-th active period. */
1   /* Perform initialization */
 1.1 $s_1^r \leftarrow 1/f; q_1 \leftarrow d_1; i \leftarrow j \leftarrow 1;$
2
 2.1 If ( $[(q_i)/(r)]$ <€ $^1/_f$ )   /* no backlog present at the start of next frame */
 2.1.1  $q_{i+1} \leftarrow d_{i+1};$
 2.1.2  $t_j^r \leftarrow {}^i/_f + [(q_i)/(r)];$   /* compute end time of current active period */
 2.1.3  $j \leftarrow j+1;$
 2.1.4  $s_j^r \leftarrow [(i+1)/(f)];$   /* start time of new active period */
 2.2 else
 2.2.1   $q_{i+1} \leftarrow q_i + d_{i+1} - {}^r/_f;$  /* there is backlog carried to current frame */
 2.3 endif
3
 3.1 $i \leftarrow i+1;$
 3.2 If ($i$ <€ $N$)
 3.2.1  goto Step 2;
 3.3 endif
4
 4.1 $s(r) \leftarrow \max_{1 \le k \le N} q_k;$   /* compute maximum queue length observed */
 4.2 $t_j^r \leftarrow {}^N/_f + [(q_N)/(r)];$   /* compute end time of last active period */
 4.3 $n_a(r) \leftarrow j;$   /* store the number of active periods */
 4.4 Define $s_{na(r)+1} = \infty;$
```

FIG. 2

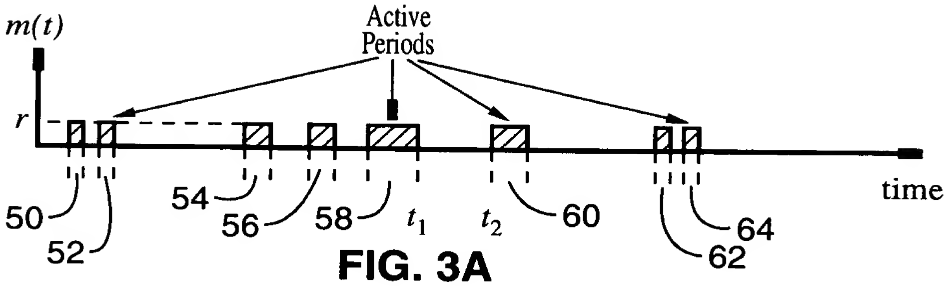

FIG. 3A

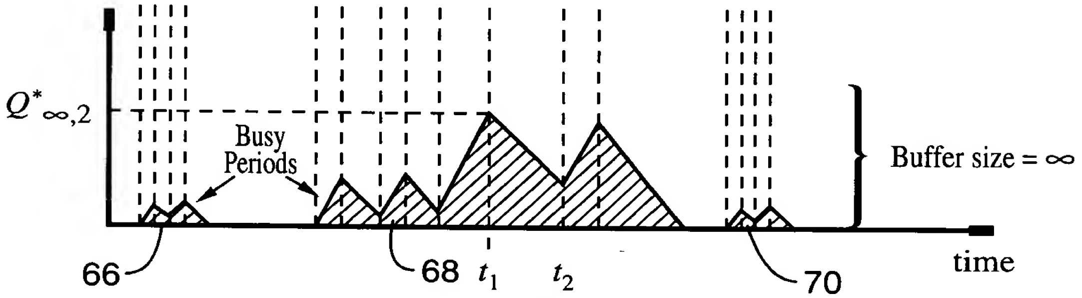

FIG. 3B

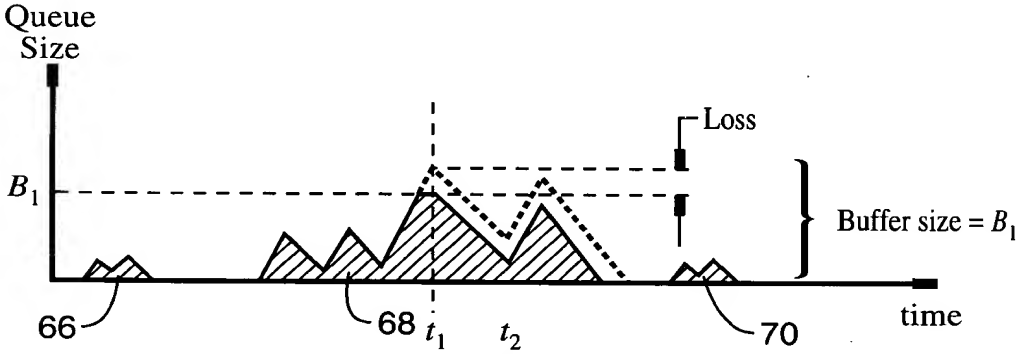

FIG. 3C

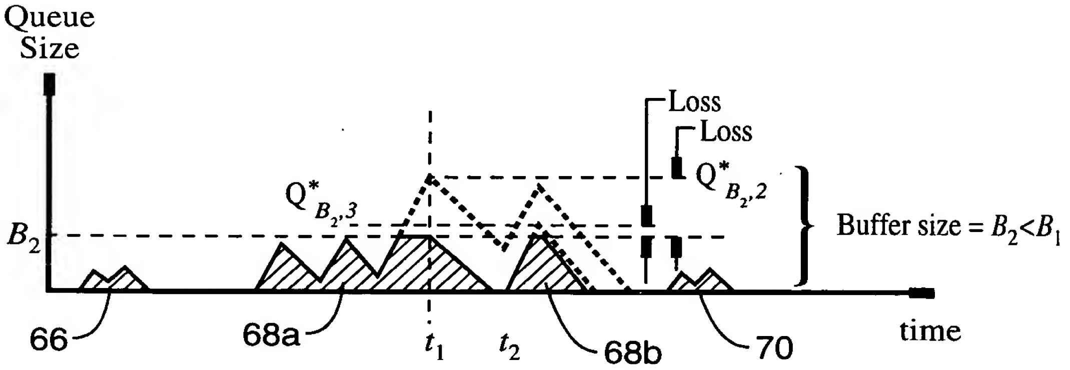

FIG. 3D

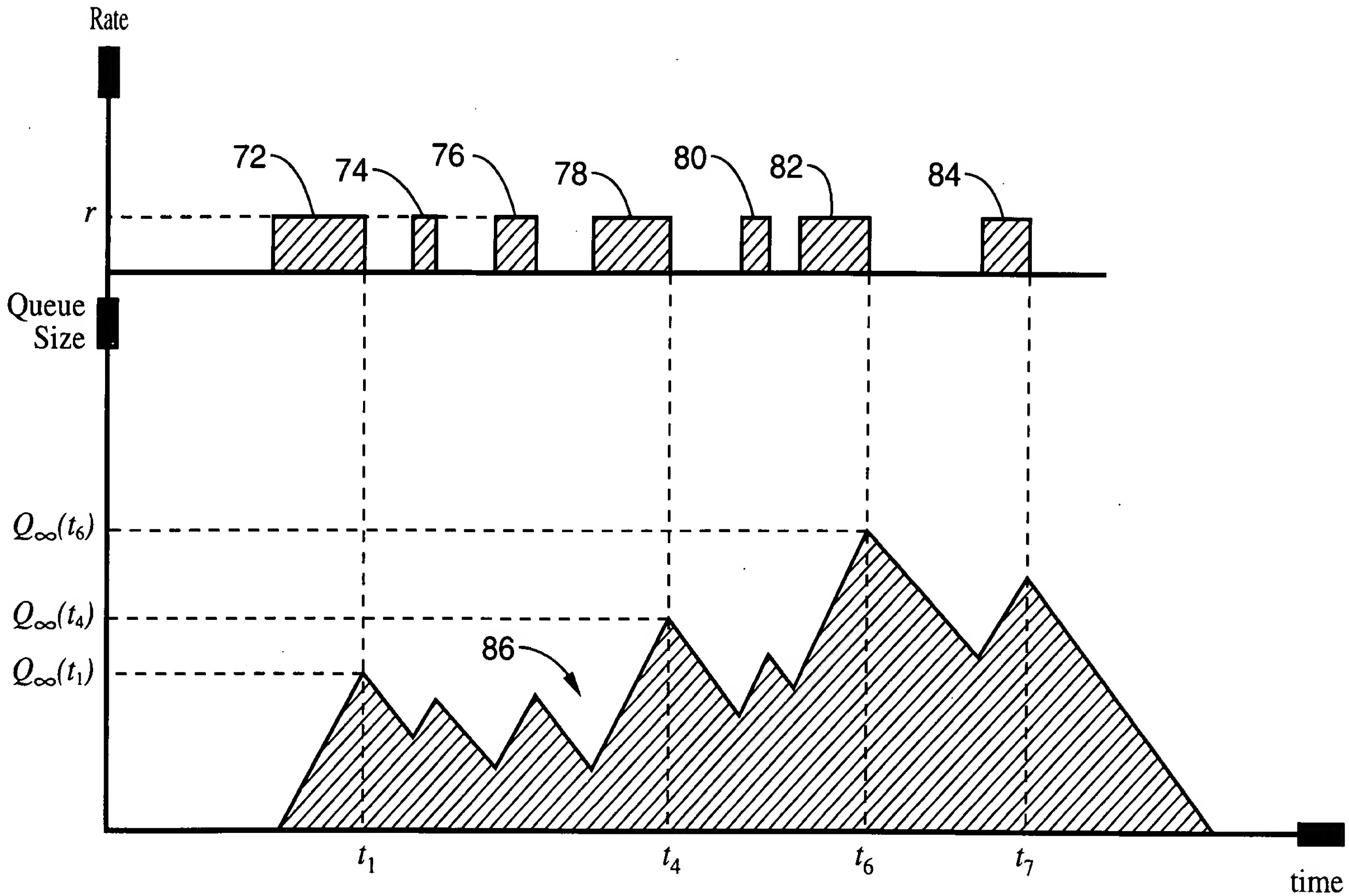
Rate
r
72
74
76
78
80
82
84
Queue Size
$Q_\infty(t_6)$
$Q_\infty(t_4)$
$Q_\infty(t_1)$
86
t_1
t_4
t_6
t_7
time

FIG. 4

```
/* ================================== */
/* ==========  Compute Loss Curve  ============ */
/* ========  for an Elementary Video Stream  ========= */
/* ================================== */
/* INIT. $B$ holds the available buffer, $L_B$ holds the sum of the unrestricted queue sizes of
the busy
periods with loss at the time instants at which the maximum queue occurs, $n_l$ holds the number
   of busy periods with loss, $n_b$ the number of busy periods, and $n_a$ the number of active periods.*/
1.1 $B \leftarrow \infty$ ; $L_B \leftarrow 0$; $n_l \leftarrow 0$; $M \leftarrow$ stream_size;
/* Compute busy periods for rate $\rho$, and buffer size $B$. */
1.2 process_active_periods(1, $n_a$, $B$);
/* Insert into the heap the buffer point at which a loss occurs
   for each busy period, compute the buffer size for the first break for
   each busy period and insert it into the heap as well. */
1.3 For $b = 1$ to $n_b$  /* for each busy period $b$ */
    1.3.1 heap_insert($Q_b^*$, LOSS, $b$);
    1.3.2 $B' \leftarrow$ compute_next_break($b$);
    1.3.3 heap_insert($B'$, BREAK, $b$);
1.4 endfor
2 /* Extract the maximum buffer from the heap, and process
   the corresponding busy period until the heap becomes empty. */
2.1 ($b$, $B$, cause) $\leftarrow$ heap_extract_max();
/* Let $(s_p, t_p), (s_{p+1}, t_{p+1}), \ldots, (s_q, t_q)$ be the active periods contained within the busy period $b$.
   Also, let $(s_p, t_p), \ldots, (s_j, t_j)$ be the active periods contained within the interval $(\alpha_b, \tau_b)$. */
2.2 If (cause = LOSS)
    /* update $n_l$ and $L_B$ variables */
    2.2.1 $L_B \leftarrow L_B + (\Sigma_{i=p}^{j} r(t_i - s_i) - \rho(t_j - s_p))$;
    2.2.2 $n_l \leftarrow n_l + 1$;
2.3 else    /* cause = BREAK */
    /* update $n_l$ and $L_B$ variables */
    2.3.1 $L_B \leftarrow L_B - (\Sigma_{i=p}^{j} r(t_i - s_i) - \rho(t_j - s_p))$;
    2.3.2 $n_l \leftarrow n_l - 1$;
    /* Process the break in busy period $b$: Compute the new busy periods, and update $n_l$ and $L_B$
       when a busy period already experiences loss. For the remaining new busy periods, insert
       into the heap the buffer points at which the first losses occur. Finally, for all the new
       busy periods, compute the buffer sizes for the first break and insert them into the heap. */
    2.3.3 process_break($b$, $B$);
2.4 endif
2.5 output_point($B$, $[(L_B - n_l B)/(M)]$);
2.6 If (heap not empty)
    2.6.1 goto Step 2;
2.7 endif
/* Output the last point of the loss curve */
2.8 Output (0, $[(r - \rho)/(r)]$);
2.9 STOP;
```

FIG. 5

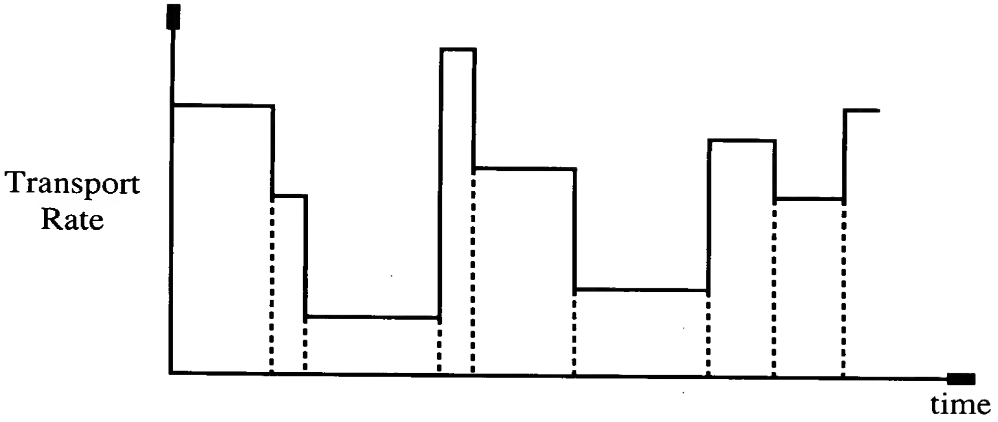
Transport Rate
time

FIG. 6

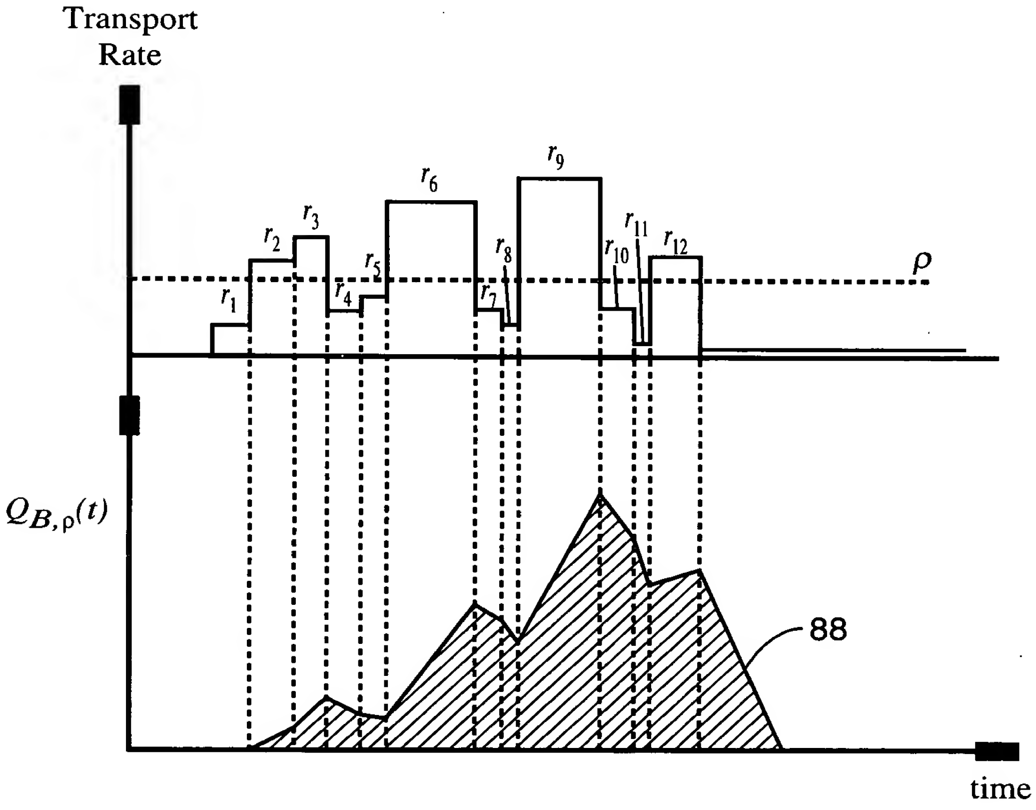
Transport Rate
r_1
r_2
r_3
r_4
r_5
r_6
r_7
r_8
r_9
r_{10}
r_{11}
r_{12}
ρ
$Q_{B,\rho}(t)$
88
time

FIG. 7

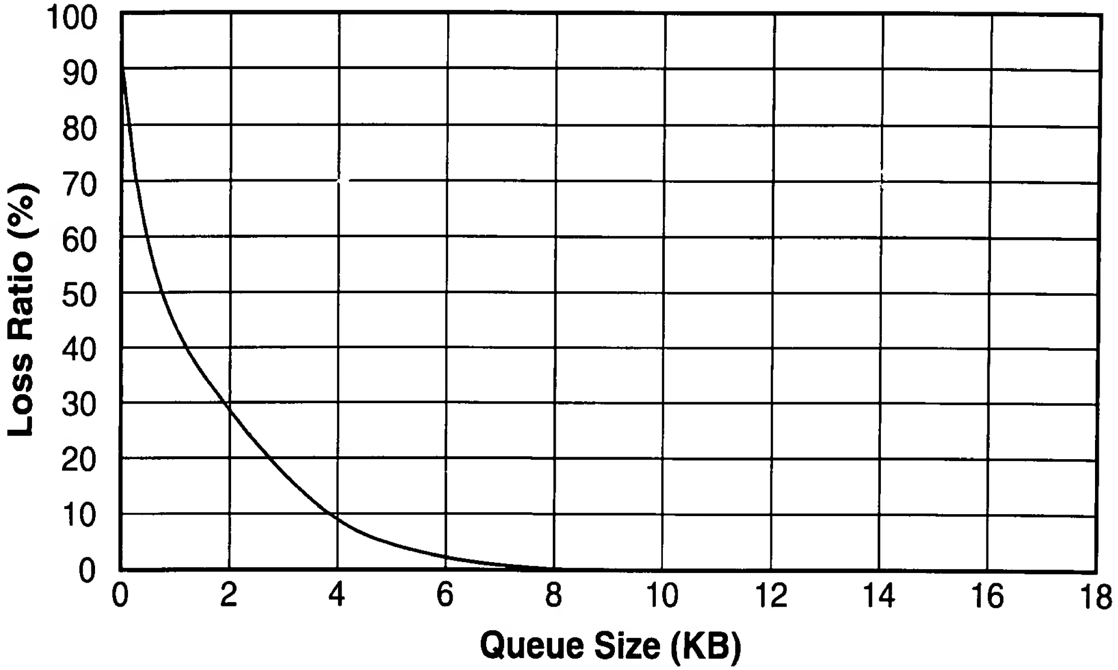
Loss Ratio (%)
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
Queue Size (KB)

FIG. 8

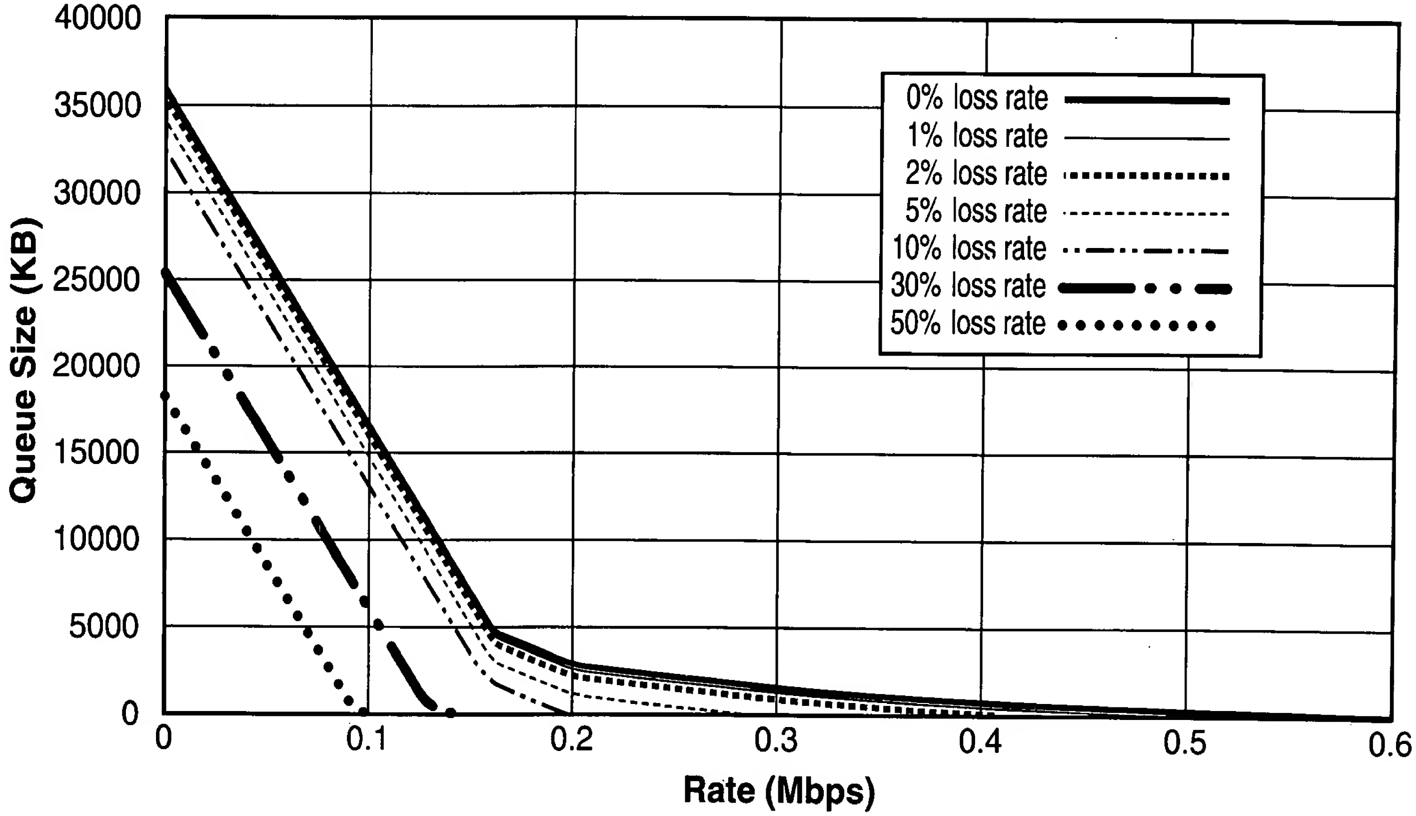
40000
35000
30000
25000
20000
15000
10000
5000
0
Queue Size (KB)
0
0.1
0.2
0.3
0.4
0.5
0.6
Rate (Mbps)
0% loss rate
1% loss rate
2% loss rate
5% loss rate
10% loss rate
30% loss rate
50% loss rate

FIG. 9